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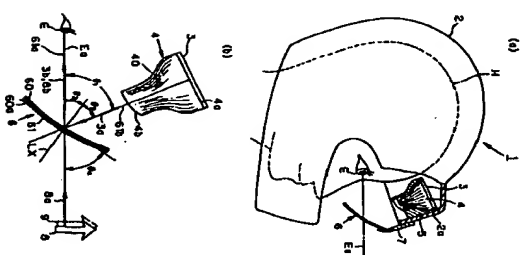
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(34) 【発明の名称】 ヘッドマウントディスプレイ

(37) 【要約】

【課題】 小型で高解像度化が図れ、カラー化が容易なヘッドマウントディスプレイを提供する。

【解決手段】 画像供給装置から画像信号がLCD3に供給されると、LCD3は、パッキナートに基づいて、画像信号に付した表示光3aを出射する。この表示光3aは、FOP4によって伝送され、出射端面4bに中間像として結像する。出射端面4bの中間像は、発光光となつてレンズ作用を有するホログラムコンバイナ6によって偏平行光束の回折光3bにされて被観者の眼Eに入射する。光量8の外界光8aは、ホログラムコンバイナ6を透過して透過光8bとして被観者の眼Eに入射する。従つて、被観者は、無限遠にLCD3からの表示光3aに基づく平面の虚像9を外界の光量8に重畳して観察することができる。



【特許請求の範囲】

【請求項1】 画像表示光を出射する画像表示手段と、前記画像表示手段からの前記画像表示光を屈折して出射端面から出射する光ファイバー束と、前記光ファイバー束の前記出射端面からの前記画像表示光を回折する回折素子とを有する前記被観者の眼Eに導き、前記被観者の眼Eに前記画像表示光に基づいて虚像を形成させる前記光学手段を備えたことを特徴とするヘッドマウントディスプレイ。

【請求項2】 前記光学手段は、外界光を前記被観者の眼Eに導く構成の前記請求項1記載のヘッドマウントディスプレイ。

【請求項3】 前記光学手段は、透明あるいは半透明のガラス、プラスチック等からなる基板と、前記基板の主面に形成されたホログラム膜を備えた構成の前記請求項1記載のヘッドマウントディスプレイ。

【請求項4】 前記光学手段は、前記被観者の視線に對して45度の角度で配置され、前記光ファイバー束からの前記画像表示光を反射させて前記被観者の眼Eに導くミラーである構成の前記請求項1記載のヘッドマウントディスプレイ。

【請求項5】 前記光学手段は、前記被観者の眼Eの凹面を向けて配置された凹面ミラーと、前記被観者の視線に對して45度の角度で配置され、前記光ファイバー束からの前記画像表示光を反射させて前記被観者の眼Eに導く凹面ミラーで反射した前記画像表示光を前記被観者の眼Eに導くミラーを備える構成の前記請求項4記載のヘッドマウントディスプレイ。

【請求項6】 前記光ファイバー束は、前記出射端面が前記被観者の眼Eを通過する所定の形状を有する構成の前記請求項1記載のヘッドマウントディスプレイ。

【請求項7】 前記光ファイバー束は、入射端面が前記画像表示手段の表示画面に密着した構成の前記請求項1記載のヘッドマウントディスプレイ。

【請求項8】 前記光ファイバー束は、前記光ファイバー束を構成する光ファイバーの数が前記画像表示手段の画素数より多い構成の前記請求項1記載のヘッドマウントディスプレイ。

【請求項9】 前記画像表示手段は、カラーの前記画像表示光を出射する構成の前記請求項1記載のヘッドマウントディスプレイ。

【請求項10】 前記画像表示手段は、カラーの前記画像表示光を出射し、前記ホログラム膜は、前記カラーの前記画像表示光に對してホログラムが記録された構成の前記請求項3記載のヘッドマウントディスプレイ。

【請求項11】 前記画像表示手段は、液晶ディスプレイ、ELディスプレイ、ガラスディスプレイ、あるいはマイクロ鏡技術によって作製されたマイクロ可動ミラーを用いたディスプレイからなる構成の前記請求項1記載のヘッドマウントディスプレイ。

【発明の詳細な説明】

【0001】 本発明は、コーン型、ヘルメット型等のヘッドマウントディスプレイに関する。特に、小型で高解像度のヘッドマウントディスプレイに関する。

【0002】 従来の技術 頭部に装着して画像を見ることのできる小型画像表示装置として、例えば、ヘッドマウントディスプレイ(HMD)が知られている。このHMDは、液晶ディスプレイ(LCD)等に代表される表示素子からなる画像表示部と、収束補正と拡大機能の備えたレンズとミラーからなる画像伝送部とを頭部に配置し、これらの画像表示部と画像伝送部とをヘルメットの装着機構で頭部に固定するものである。動画像を画像表示部の表示素子で表示すると、この表示された動画像は、画像伝送部のレンズとミラーが有する収束補正と拡大機能によって只やすい場所で大画面の仮想スクリーンで表示され、被観者に提示される。

【0003】 この種のHMDは、航空機用として高度、速度等の飛行情報を表示するものから、個人ビデオ用として映画、テレビゲーム、人工現実感を表示するものが開発され、製品化されている。また、最近では、携帯型コンピュータ(portable computer)用のディスプレイとしての研究も始まっている。

【0004】 このようなHMDには、外界を見ることのできるシーソー型と、外界を見ることのできないクロース型がある。人工現実感を表示する場合は、クロース型の方が好ましい場合もあるが、携帯用としては大抵の場合、シーソー型の方が向いている。シーソー型のHMDは、上記画像表示部および画像伝送部の他に、シーソー機能を持つビームコンバイナを備える。このビームコンバイナは、特定の波長に對して強い波長選択性があり、その波長のみを反射あるいは回折させることができるため、特定の波長の100%の画像表示光とその他の波長を除いた100%の外界光を重ねて見ることができ、

【0005】 図4は、シーソー型の従来のHMDとして、例えば、米国特許第5,035,474号に示されているものを示す。このHMD100は、画像表示面101に画像を表示するCRTと、画像表示面101から出射された表示光101aを中間結像面102に結像させるプリズムシステム103およびリレーレンズ104と、中間結像面102から発光光101aを略平行光束として被観者の眼Eに入射するホログラ

とが配置されている。これらのLCD3およびFOP4は、ホルダ5によって上部21aに保持されている。また、投光Ea上には、装着者の眼Eに凹面を向けて配置された拡大機能を有する眼前光手段としての凹面ハーフミラー62と、装着者の視軸Eaに対して45度の角度で配置され、FOP4からの表示光3aを凹面ハーフミラー62へ反射させてその凹面ハーフミラー62でさらに反射した表示光を装着者の眼Eに導く眼前光手段としてのハーフミラー63とが配置されている。凹面ハーフミラー62は、ゴニアル21の前方の開口部21bに設けられ、ハーフミラー63は、前部21bの内部に設けられている。

【0020】LCD3は、ゴニアル21に収容するため、第1の実施の形態よりも小さなサイズ、例えば、600×1200の72万画素を備え、1.4インチの20mm×28mmのサイズを有している。

【0021】FOP4は、入射側の太さが6μm、出射側の太さが2μmのテーパー状3:1の形状を有する1980万本の光ファイバー40を束ねたものであり、入射端面4aがLCD3に密着し、入射端面4aのサイズがLCD3と同一の20mm×28mm、出射端面4bのサイズが約6.6mm×9.4mmとなっている。また、FOP4は、第1の実施の形態と同様に、出射端面4bが、装着者が平面の虚像8を觀察できるように垂直した面となっている。

【0022】次に、第2の実施の形態に係るHMD1の動作を説明する。図示しない画像供給装置から画像信号がLCD3に供給されると、LCD3は、バックライトに基づいて、画像層身に付いた表示光3aを射出する。この表示光3aは、FOP4によって伝送され、出射端面4bに中間像として結像する。出射端面4bの中間像は、発散光となってハーフミラー63に入射し、その反射光3cがハーフミラー62で反射して拡大機能を有する凹面ハーフミラー62に入射し、その一部が反射して集束光3dにされ、ハーフミラー63を透過して透過光3eとして装着者の眼Eに入射する。光路8の外界光8aは、凹面ハーフミラー62およびハーフミラー63を透過して透過光8bとして装着者の眼Eに入射する。従って、觀察者は、無限遠にLCD3からの表示光3aに基づく拡大された平面の虚像8を外景8に重ねて觀察することができる。

【0023】次に、本発明の第3の実施の形態に係るHMDについて説明する。この第3の実施の形態は、図1に示す第1の実施の形態に係るHMD1をカラー化している。この第3の実施の形態は、赤(R)、緑(G)、青(B)の三原色光からなる表示光を射出するカラーLCDを用い、R、G、Bの三原色光に対向したホログラムコンバイナ6を用いる。R、G、Bの三原色光に対向したホログラムコンバイナ6を作製するには、図2に示

すホログラム製作装置10において、He-Neレーザ11の代わりに、R用としてヘリウムネオンレーザ(632.8nm)、G用としてホログラムを記録し、G用としてYAG-SHGLレーザ(532nm)を用いてホログラムを記録し、B用としてアルゴンレーザ(488nm)を用いてホログラムを記録する。この第3の実施の形態によれば、小型でありながら、カラーの虚像を表示することができる。

【0024】なお、本発明は、上記実施の形態に限定されず、種々な形態が可能である。例えば、図3の構成において、凹面ハーフミラー62を設けず、FOP4からの表示光3aを装着者の眼Eに反射させるように投光Eaに対して45度の角度でハーフミラー63を配置してもよい。また、上記実施の形態では、シーソー型について説明したが、クローズ型にてもよい。この場合は、外界光が装着者の眼Eに入らないように基板の外側の面(LCDからの表示光が入射する面と反対の面)に遮光シートを貼ってもよく、ヘルメットやゴニアル等の他の部材で基板全体を覆ってもよい。また、第1の実施の形態では、基板の外側の面にホログラム像を形成したが、基板の内側の面に形成してもよい。

【0025】
【発明の効果】以上説明した通り、本発明によれば、光ファイバー束を用いることで、レンズ系を用いなくとも所望の中間結像面を得ることができるので、小型化が図れる。また、画像表示手段からの画像表示光を光ファイバー束によって輸しているため、画素数の多い画像表示手段を用いることができることから、高解像度の虚像を表示することができる。この結果、カラー化が容易となる。

【図面の簡単な説明】

【図1】本発明の第1の実施の形態に係るHMDを示し、(a)はその側面図、(b)はその光路系を示す図である。
【図2】第1の実施の形態に係るホログラム製作装置の概略構成図である。
【図3】本発明の第2の実施の形態に係るHMDを示し、(a)はその側面図、(b)はその光路系を示す図である。

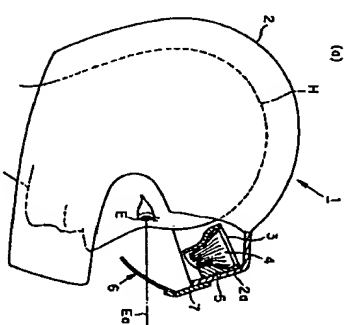
【図4】従来のHMDの構成図である。

【符号の説明】

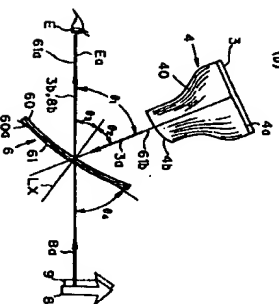
- 1 ヘッドマウントディスプレイ(HMD)
- 2 ヘルメット
- 2a 前方部
- 3 液晶ディスプレイ(LCD)
- 3a 表示光
- 3b 回折光
- 3c 反射光
- 3d 集束光
- 3e 透過光

- 4 フライバーステアリングユニット(FOP)
- 4a 入射端面
- 4b 出射端面
- 5 ホルダ
- 6 ホログラムコンバイナ
- 7 取付部材
- 8 光路
- 8a 外界光
- 8b 透過光
- 9 虚像
- 10 ホログラム製作装置
- 11 He-Neレーザ
- 12A, 12B, 12C ミラー
- 13 ハーフミラー
- 14A, 14B 拡大レンズ
- 15 コリメータレンズ

【図1】

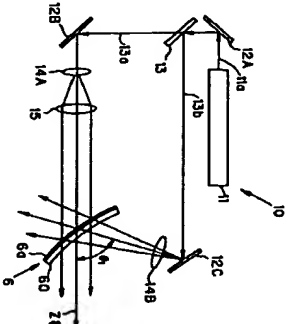


(b)

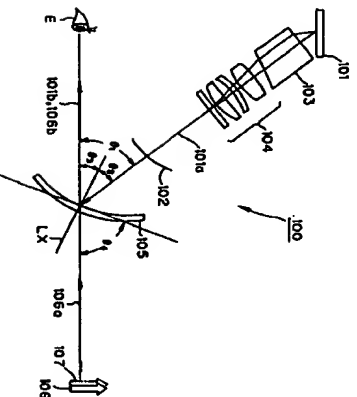


- 20 ヘルメット
- 21 ゴニアル
- 21a 上部
- 21b 開口部
- 21b 前部
- 40 光ファイバー
- 60 基板
- 60a 主面
- 61 ホログラム像
- 61a 第1の光軸
- 61b 第2の光軸
- 62 凹面ハーフミラー
- 63 ハーフミラー
- E 眼
- H 頭部

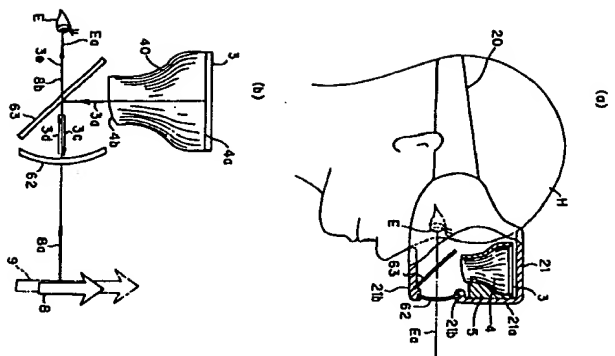
【図2】



【図4】



【図3】



**A Translation of Substantially the Whole of
Japanese Patent Application Laid-Open No. H10-319343
(Laid-Open on December 4, 1998)**

5 [Title of the Invention]

Head-Mounted Display

[Abstract]

[Object] To provide a compact and high resolution head-mounted
10 display that readily achieves projection of color images.

[Features] If an image signal is fed to an LCD 3 from an image feeder, the LCD 3 emits, in accordance with backlight, display light 3a corresponding to the image signal. The display light 3a is conveyed by an FOP 4 and focused on an exit end face 4b as an intermediate image. The intermediate image formed on the exit
15 end face 4b becomes divergent light, then is converted into diffracted light 3b composed of substantially parallel beams by a hologram combiner 6 having a function as a lens element, and then enters a user's eye E. The external light 8a from a view 8 passes through the hologram combiner 6, and enters the user's eye E as transmitted light 8b. Therefore, the user can infinitely observe a flat virtual
20 image 9 formed in accordance with the display light 3a emitted from the LCD 3 while superimposing it on the outside view 8.

[Claims]

[Claim 1] A head-mounted display comprising:
25 an image display means for emitting display light;
a bundle of optical fibers that makes the display light emitted from the image display means exit from an exit end face while reducing it; and
an in-front-of-eye optical means that directs the display light exited from the exit end face of the bundle of optical fibers to the user's eye by diffracting or
30 reflecting it so as to permit a user to observe a virtual image formed in accordance with the display light.

[Claim 2] A head-mounted display as claimed in claim 1,
wherein the in-front-of-eye optical means directs external light to the user's
eye.

5 [Claim 3] A head-mounted display as claimed in claim 1,
wherein the in-front-of-eye optical means is provided with a substrate made
of transparent or semitransparent glass, plastics, or the like, and a hologram film
formed on a principal plane of the substrate.

[Claim 4] A head-mounted display as claimed in claim 1,
wherein the in-front-of-eye optical means is obliquely arranged relative to a
10 visual axis of the user's eye at 45°, and directs the image light exited from the
bundle of optical fibers to the user's eye by reflecting it.

[Claim 5] A head-mounted display as claimed in claim 4,
wherein the in-front-of-eye optical means is provided with a concave mirror
concave to the user's eye, and a mirror obliquely arranged relative to the visual axis
15 of the user's eye at 45° that reflects the image light exited from the bundle of optical
fibers toward the concave mirror in order to direct the image light reflected on the
concave mirror to the user's eye.

[Claim 6] A head-mounted display as claimed in claim 1,
wherein the bundle of optical fibers includes the exit end face having a
20 predetermined shape suitable for correcting aberrations of a virtual image.

[Claim 7] A head-mounted display as claimed in claim 1,
wherein the bundle of optical fibers has an incident end face closely
attached to the image display means.

[Claim 8] A head-mounted display as claimed in claim 1,
25 wherein the bundle of optical fibers is composed of a larger number of
optical fibers than pixels of the image display means.

[Claim 9] A head-mounted display as claimed in claim 1,
wherein the image display means emits color display light.

[Claim 10] A head-mounted display as claimed in claim 3,
30 wherein the image display means emits color display light, and the hologram

film is formed by recording a hologram in accordance with the color display image.

[Claim 11] A head-mounted display as claimed in claim 1,

wherein the image display means is realized as a liquid crystal display, an EL display, a plasma display, or a display using a micro-variable mirror made by a micromachining method.

[Claim 12] A head-mounted display as claimed in claim 1,

wherein the image display means, the bundle of optical fibers, and the in-front-of-eye optical means are equipped to a goggle or helmet.

10 [Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a head-mounted display such as goggle- or helmet-type, and more particularly to a head-mounted display that is compact and high resolution.

[0002]

[Prior Art]

As a compact image display that permits observation of images while being mounted on a head, for example, a head-mounted display (HMD) is widely known. In an HMD, an image display portion composed of an image display device such as a liquid crystal display (LCD), and an image transmission portion comprising a lens element and a mirror having an aberration correcting function and a magnifying function are arranged in front of an observer's eye. And the image display portion and the image transmission portion are fixed on a head with a mounting tool such as a belt. If a dynamic image is displayed on the image display device of the image display portion, owing to the aberration correcting function and the magnifying function of the lens element and the mirror, the displayed dynamic image is projected on a large virtual screen at a place easy to see, and then is observed by a user.

30 [0003]

Several HMDs of this type have been developed and manufactured including a display for use in an airplane for displaying flight information such as its altitude and speed, and a display for use in a personal theater for displaying movies, TV games, or images of virtual reality. In recent years, a study for a display for use in a portable computer (wearable computer) has been launched.

[0004]

There are two types of such HMD, namely a see-through type HMD that permits observation of outside, and a close-type HMD that prohibits observation of outside. In a field of artificial reality, in some cases, it is desirable to use a close-type HMD; however, for use as a portable display, a see-through type HMD is more desirable generally. In addition to the image display portion and the image transmission portion, the see-through type HMD is provided with a beam combiner having a see-through function. This beam combiner exhibits a strong wavelength selectivity against a specific wavelength, and this makes it possible to reflect or diffract only the light having the specific wavelength. Therefore, it is possible to observe an image while superimposing display light 100% consisting of the specific wavelength on 100% of the external light excluding the specific wavelength.

[0005]

Fig. 4 shows, as an example of conventional HMD, an HMD disclosed in United States Patent No. 5,035,474. This HMD 100 includes a CRT for displaying an image on an image display surface 101, a prism system 103 and a relay lens 104 for imaging image light 101a exited from the image display surface 101 on an intermediate image plane 102, and a hologram combiner for making the display light 101a exited from the intermediate image plane 102 as divergent light become a parallel pencil of rays and enter an observer's eye E. The intermediate image plane 102 is formed as a distorted surface for enabling an observer to observe a flat virtual image 107. The angle θ , which the optical axis of the prism system 103 and the relay lens 104 makes with horizontal external light 106a exiting from an external view 106 is set at 58° ; the angle formed between the normal line axis LX of the hologram combiner 105 and the optical axis of the relay lens 104, in other

words, the incident angle θ_2 of the display light 101a entering the hologram combiner 105 from the relay lens 104, is set at 27.76° ; and the angle which the normal line axis LX of the hologram combiner 105 makes with diffracted light 101b of the display light 101a exited from the relay lens 104 and transmitted light 106b of the external light 106a, i.e. a reflection angle θ_3 , is set at 30.24° . The hologram combiner 105 is obliquely arranged on an unillustrated visor, as an inclination angle θ_4 , at 59.7° .

[0006]

In the above-mentioned HMD 100, by passing through the prism system 103 and the relay lens 104, the display light 101a emitted from the image displayed on the image display surface 101 is focused on the intermediate image plane 102 as an intermediate image. The intermediate image formed on the intermediate image plane 102 becomes divergent light, then is made to be diffracted light 101b composed of a substantially parallel pencil of rays, and then enters the observer's eye E. The external light 106 of the view 107 passes through the hologram combiner 105, and enters the observer's eye E as transmitted light 106b. Therefore, the observer can infinitely observe a flat virtual image 107 formed in accordance with the display light 101a emitted from the image display surface 107 of a CRT while superimposing it on the external view 106. Here, the diffracted light 106b of the display light 101 and the transmitted light 106a of the external light 106a are not decreased in terms of the quantity of light.

[0007]

[Problems to be Solved by the Invention]

However, the conventional HMD 100 uses a complicated lens system composed of the prism system 103 and the relay lens 104 for obtaining a flat virtual image 107, and therefore it has disadvantage of becoming unduly large. In order to improve its resolution, the display requires a larger CRT; however, if the CRT becomes larger, the complicated lens system composed of the prism system 103 and the relay lens 104 also becomes larger, and therefore the conventional HMD has disadvantage of having a limitation in improving resolution thereof because of

its spatial restriction. Furthermore, because the hologram combiner 105 is of a single color, it is difficult to offer color images.

[0008]

An object of the present invention is to provide a compact and high-resolution head-mounted display. Another object of the present invention is to provide a head-mounted display readily achieves projection of color images.

[0009]

[Means for Solving the Problem]

To achieve the above object, the present invention provides a head-mounted display comprising: an image display means for emitting display light; a bundle of optical fibers that makes the display light emitted from the image display means exit from an exit end face while reducing it; and an in-front-of-eye optical means that directs the display light exited from the exit end face of the bundle of optical fibers to the user's eye by diffracting or reflecting it in such a manner that permits a user to observe a virtual image formed in accordance with the display light.

[0010]

[Embodiments of the Invention]

Figs. 1(a) and 1(b) show a head-mounted display (hereinafter, referred to as an HMD) of a first embodiment of the present invention, in which Fig. 1(a) is a side view thereof and Fig. 1(b) shows the optical system thereof. This HMD 1 is a helmet-type HMD having a helmet 2 mountable on a head. And, inside of a front portion 2a of the helmet 2, a liquid crystal display (LCD) 3 equipped with a backlight that serves as an image display means for emitting display light 3a, and a fiber optics plate (FOP) 4 that emits the display light 3a received from the LCD 3 while reducing it are arranged. The LCD 3 and the FOP 4 are held in the front portion 2a by a holder 5. On a visual axis Ea, a hologram combiner 6 is arranged as an in-front-of-eye optical means that diffracts the display light 3a emitted from the FOP 4 and directs it to the user's eye E as diffracted light 3b. This hologram combiner 6 is attached in the front portion 2a by an attaching member 7.

[0011]

For example, the LCD 3 is provided with 2,880,000 pixels (1200×2400) and has a size of 2.8-inch ($40 \text{ mm} \times 56 \text{ mm}$). As an image display means, it is also possible to use such as a reflection-type LCD, an EL display, a plasma display, or a display using a micro-variable mirror made by a micromachining method; however, among which, an LCD is the most preferable from the perspective of miniaturizing the display.

[0012]

The FOP 4 is so designed as to emit the display light 3a received from the LCD 3 while reducing it at a predetermined reduction ratio, e.g. $1/3$. In other words, the FOP 4 is made by bundling 79,200,000 of optical fibers having the diameters of $6 \mu\text{m}$ in its incident side and $2 \mu\text{m}$ in its exit side, of which taper ratio is 3:1. The FOP 4 has an incident end face 4a closely attached to the LCD 3. Here, the size of the incident end face 4a is identical to that of the LCD, namely $40 \text{ mm} \times 56 \text{ mm}$, and the size of the exit end face 4b is $13.2 \text{ mm} \times 18.8 \text{ mm}$. The exit end face 4b is formed as a distorted surface such as a substantially convex spherical surface for enabling a user to observe a virtual image 9 formed ahead of the hologram combiner 6 as a flat image.

[0013]

The hologram combiner 6 is provided with a transparent or a semitransparent substrate 60 made of glass such as PYREX glass or soda glass, plastics, or the like, and a hologram film 61 formed on the principal surface 60a (e.g. the face opposite to which the display light 3a from the LCD 3 enters) of the substrate 60. The hologram film 61 is made by applying a holographic photosensitive material to the substrate 60 and following the steps described below. As the holographic photosensitive material, it is also possible to use, for example, photopolymer, a photoresistive material, a photochromic material, a photodichromic material, silver salt emulsion, dichromic acid gelatin, dichromate gelatin, plastics, a ferroelectric substance, a magneto-optical material, an electro-optical material, an amorphous semiconductor, or a photorefractive material. A protective coat may be deposited on the surface thereof for protecting the hologram

film 61. As the protective coat, it is possible to use amorphous polyolefine, polycarbonate (PC), polymethyl methacrylate (PMM), perfluoro alkoxide polyethylene (PFA), or the like. In the HMD embodying the present invention, the hologram combiner 6 is concave to the user's eye E; however, it can be a flat surface.

5 [0014]

The hologram film 61 forms a small asymmetric optical system. In other words, the hologram film 61 has a first optical axis 61a coinciding with the visual axis Ea, and a second optical axis 61b inclined to the first optical axis at θ_1 , for example, 58° . Here, the angle which the normal line axis LX of the hologram combiner 6 makes with the optical axis of the LCD 3 and the FOP 4, in other words, an incident angle θ_2 of the display light 3a entering the hologram combiner 6 from the FOP 4, is set at, for example, 27.76° ; and the angle which the normal line axis LX of the hologram combiner 6 makes with diffracted light 3b of the display light 3a exited from the FOP 4 and transmitted light 8b of the external light 8a, i.e. a reflection angle θ_3 , is set at, for example, 30.24° . The hologram combiner 6 is obliquely mounted on the helmet 2, as an inclination angle θ_4 , at 59.7° .

[0015]

Fig. 2 shows a hologram-film-manufacturing device for manufacturing the hologram film 61. The hologram-film-manufacturing device 10 is provided with an He-Ne laser 11, a first, a second, and a third mirror 12A, 12B, and 12C, a half mirror 13, a first and a second magnifying lens 14A and 14B, and a collimeter lens 15.

[0016]

First, on the principal surface 60a of the substrate 60, as a holographic photosensitive material, for example, photopolymer 6a is spin-coated. Here, it is possible to form a film of photopolymer 6a having an even thickness distribution by controlling the rotational speed and others. Then, the substrate 60 with the photopolymer 6 formed thereon is disposed in the predetermined area as shown in Fig. 2. If a laser beam 11a is emitted from the He-Ne laser of the hologram-film-manufacturing device, the laser beam 11a is turned its direction by the first mirror

12A, and then is split into two beams 13a and 13b by the half mirror 13. The beam 13a passed through the half mirror 13 is turned its direction by the second mirror 12B, then is converted into a divergent wave by the first magnifying lens 14A, and then is converted into a plane wave by the collimeter lens 15. The other
 5 beam 13b reflected on the half mirror 13 is turned its direction by the third mirror 12C, and is converted into a divergent wave by the second magnifying lens 14B. The divergent wave enters the photopolymer 6a from the back side thereof in a manner such that the angle θ_1 formed between the optical axis of the divergent wave and the Z-axis is identical to θ_1 shown in Fig. 1(b). The beam 13a entering
 10 from the front face of the photopolymer 6a and the beam 13b entering from the back side of the photopolymer 6a form interference fringes on the photopolymer 6a. The interference fringes formed on the photopolymer 6a undergoes a developing process for recording a hologram, and thus the hologram film 61 is obtained. Here, a process for manufacturing the hologram film 61 by using a plane wave and a
 15 divergent wave is explained; however, it is possible to manufacture it by using a convergent wave and a divergent wave.

[0017]

Then, the operation of the HMD 1 used in the first embodiment will be explained below. If an image signal is fed to the LCD 3 from an unillustrated
 20 image feeder, the LCD 3 emits, in accordance with backlight, display light 3a corresponding to the image signal. The display light 3a is conveyed by the FOP 4 and focused on the exit end face 4b as an intermediate image. The intermediate image formed on the exit end face 4b becomes divergent light, then is converted into diffracted light 3b composed of a substantially parallel pencil of rays by the
 25 hologram combiner 6 having a function as a lens element, and then enters the user's eye E. External light 8a of the view 8 is transmitted through the hologram combiner 6, and then enters the user's eye E as transmitted light 8b. Therefore, the user can infinitely observe a flat virtual image 9 formed in accordance with the display light 3a emitted from the LCD 3 while superimposing it on the view 8 of the
 30 outside.

[0018]

Then, the advantages of the HMD 1 employed in the first embodiment will be described.

(1) The exit end face 4b of the FOP 4 serves as the intermediate image plane, and this eliminates the need for forming an intermediate image plane by the use of a lens system. Furthermore, since the LCD 3, the FOP 4, and the hologram combiner 6 can be incorporated in the helmet 2, it is possible to miniaturize the HMD 1.

(2) Since the display light 3a emitted from the LCD 3 is reduced by FOP 4, the LCD 3 having a large number of pixels can be used, and this makes it possible to display a high-resolution virtual image 9.

(3) The exit end face 4b of the FOP 4 has a shape suitable for correcting aberrations of the virtual image 9, and this makes it possible to observe the flat virtual image 9.

(4) If this HMD 1 is employed as an HMD for use in an airplane, it is possible to observe outside and flight information simultaneously, and if this HMD 1 is employed as an HMD for use in a vehicle, it is possible to observe outside and traffic information simultaneously. This enables the user to exhibit excellent instantaneous information gathering ability during flight or drive.

[0019]

Figs. 3(a) and 3(b) show an HMD of a second embodiment of the present invention, in which Fig. 3(a) is a side view thereof and Fig. 3(b) shows the optical system thereof. This HMD 1 is a goggle-type HMD having a goggle 21 held on a head with a headband 20. And, in an upper portion 21a of the goggle, an LCD 3 equipped with backlight that serves as an image display means for emitting display light 3a perpendicular to a visual axis, and an FOP 4 that emits the display light 3a received from the LCD 3 while reducing it are arranged. The LCD 3 and the FOP 4 are held in the upper portion 21a by a holder 5. On the visual axis Ea, a concave half mirror 62 concave to the user's eye E is arranged as an in-front-of-eye optical means having a magnifying function, and, a half mirror 63 is arranged as an in-

front-of-eye optical means that is obliquely arranged at 45° relative to the user's visual axis Ea , that makes the display light 3a emitted from the FOP 4 reflect toward the concave half mirror 62, and that directs the display light reflected by the concave half mirror 62 to the user's eye E. The concave half mirror 62 is disposed in an aperture 21b in a front portion of the goggle 21, and the half mirror 63 is held inside of the front portion 21b.

[0020]

In order to be held inside of the goggle 21, the size of the LCD 3, here, is smaller than that of the first embodiment. For example, an LCD having 720,000 pixels (600×1200) of which size is 1.4-inch ($20 \text{ mm} \times 28 \text{ mm}$) is used.

[0021]

The FOP 4 is made by bundling 19,800,000 of optical fibers having the diameters of $6 \mu\text{m}$ in its incident side and $2 \mu\text{m}$ in its exit side, of which taper ratio is 3:1. The FOP 4 has an incident end face 4a closely attached to the LCD 3 of which size is identical to that of the LCD 3, i.e. $20 \text{ mm} \times 28 \text{ mm}$, and has the exit end face 4b of which size is $6.6 \text{ mm} \times 9.4 \text{ mm}$. As in the first embodiment, the exit end face 4b is formed as a distorted surface so that an observer can observe a flat virtual image 9.

[0022]

Then, the operation of the HMD 1 employed in the second embodiment will be explained below. If an image signal is fed to the LCD 3 from an unillustrated image feeder, the LCD 3 emits, in accordance with backlight, display light 3a corresponding to the image signal. The display light 3a is conveyed by the FOP 4 and focused on the exit end face 4b as an intermediate image. The intermediate image formed on the exit end face 4b becomes divergent light and enters the half mirror 63. Thereafter, the reflected light 3c is reflected from the half mirror 63 and enters the concave half mirror 62 having a magnifying function. Thereafter, a portion thereof becomes focused light 3d upon being reflected, then passes through the half mirror 63, and then enters the user's eye E as transmitted light 3e. The external light 8a of the view 8 passes through the concave half mirror 62a and the

half mirror 63, and then enters the user's eye E as transmitted light 8b. Therefore, the observer can infinitely observe a flat virtual image 9 formed in accordance with the display light 3a emitted from the LCD 3 while superimposing it on the view 8 of the outside.

5 [0023]

Then, an HMD employed in a third embodiment of the present invention will be explained below. The HMD used in the third embodiment is similar to the HMD 1 in the first embodiment shown in Fig. 1 with exception that it achieves projection of color images. In other respects, the construction here is the same as
10 in the first embodiment. The third embodiment uses a color LCD for emitting display light of three primary colors, namely red (R), green (G), and blue (B), and uses a hologram combiner 6 corresponding to the three primary colors R, G, and B. The hologram combiner 6 corresponding to the three primary colors R, G, and B can be manufactured in the following manner. That is, in the hologram-film-
15 manufacturing device 10 shown in Fig. 2, instead of the He-Ne laser 11, for recording a hologram, a helium-neon laser (632.8 nm) is used for R, a YAG-SHG laser (532 nm) is used for G, and an argon laser (488 nm) is used for B. According to the third embodiment, it is possible to obtain a small-sized display but that nevertheless offers color images.

20 [0024]

It is to be understood that the present invention may be practiced in any other manner than is specifically described in the embodiments. For example, in the construction shown in Fig. 3, it is possible to eliminate the concave half mirror 62, and, instead, the half mirror 63 is obliquely arranged at 45° relative to the visual
25 axis Ea in order to reflect the display light 3a emitted from the FOP 4 toward the user's eye E. In the above-mentioned embodiment, a see-through type HMD is described; however, a close-type HMD may be used instead. In this case, a light-shielding sheet may be applied to the outside face of a substrate (e.g. the face opposite to which the display light from the LCD enters) for preventing external
30 light from entering the user's eye, and it is also possible to cover the whole

substrate with other member including a helmet, a goggle, or the like. In the first embodiment, a hologram film is formed on the outside face of the substrate; however, it can be formed on the inside face thereof.

[0025]

5 [Advantages of the Invention]

As described above, according to the present invention, by using optical fibers, it is possible to obtain a desired intermediate image plane without using a lens system, and this helps miniaturize HMDs. Furthermore, since the display light emitted from the image display means is reduced by the bundle of optical
 10 fibers, an image display means having a large number of pixels can be used, and this makes it possible to display a high-resolution virtual image. As a result, it is possible to readily achieve projection of color images.

[Brief Description of the Drawings]

15 [Fig. 1] Diagrams illustrating an HMD of a first embodiment of the present invention, in which (a) is a side view thereof and (b) shows the optical system thereof.

[Fig. 2] A diagram illustrating the outline of the construction of a hologram-film-manufacturing device used in the first embodiment of the present
 20 invention.

[Fig. 3] Diagrams illustrating an HMD of a second embodiment of the present invention, in which (a) is a side view thereof and (b) shows the optical system thereof.

[Fig. 4] A diagram illustrating a conventional HMD.

25 [Reference Numerals]

1	Head-Mounted Display (HMD)
2	Helmet 2
2a	Front Portion
3	Liquid Crystal Display (LCD)
30 3a	Display Light

	3b	Diffracted Light
	3c	Reflected Light
	3d	Focused Light
	3e	Transmitted Light
5	4	Fiber Optics Plate (FOP)
	4a	Incident End Face
	4b	Exit End Face
	5	Holder
	6	Hologram Combiner
10	7	Attaching Member
	8	View
	8a	External Light
	8b	Transmitted Light
	9	Virtual Image
15	10	Hologram-Film-Manufacturing Device
	11	He-Ne Laser
	12A, 12B, 12C	Mirrors
	13	Half Mirror
	14A, 14B	Magnifying Lenses
20	15	Collimeter Lens
	20	Head Band
	21	Goggle
	21a	Upper Portion
	21b	Aperture
25	21b	Front Portion
	40	Optical Fiber
	60	Substrate
	60a	Principal Surface
	61	Hologram Film
30	61a	First Optical Axis

61b	Second Optical Axis
62	Concave Half Mirror
63	Half Mirror
E	Eye
5 H	Head